

## METHOD AND APPARATUS FOR TIME VARYING SPECTRUM ANALYSIS

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### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

The present invention relates to digital signal processing; and more particularly, to machines and methods for determining characteristics of signals having frequency components that vary in time.

#### 2. Description of the Related Art

Typical systems for digital signal processing involve conversion of an input analog signal to a sequence of digital samples, supplying blocks of the digital samples in the sequence to a digital signal processing engine which performs array or block level computations on the digital signals, and analyzing the results of the computations. This field is rapidly expanding in the areas of speech processing, image recognition for radar and sonar, underwater acoustics, and other technologies.

The discrete Fourier transform DFT and fast Fourier transform FFT implementation of the DFT, are fundamental processing techniques in digital signal processing systems. These techniques suffer the limitation that they do not characterize signals being processed in terms of how frequency components vary in time very well.

Prior art systems for analyzing signals with frequency components that vary in time have used the so-called short time Fourier transform STFT. This algorithm is based on a computationally intensive Fourier transform of a large number of short windows of the input signal. Transforms of each of the short time windows are combined to generate a time varying spectrum of the input signal. However, time varying spectra generated using the STFT technique do not have very good resolution. Also, the STFT technique is computationally expensive.

The Gabor transform is another digital signal processing tool which generates a joint time-frequency representation of a signal. See, D. Gabor, "Theory of Communication", J.IEE (London), Vol. 93, No. III, November, 1946, pp. 429-457. Its applications, however, have been limited primarily due to the difficulty of selecting the biorthogonal auxiliary window function  $\gamma$ . Recently, a framework for designing the auxiliary function  $\gamma$  for the finite and cyclic discrete Gabor transform has been developed. See, Wexler, et al., "Discrete Gabor Expansions", *Signal Processing*, Vol. 21, No. 3, November, 1990, pp. 207-221. In many signal processing applications, however, the finite, cyclic Gabor transform is not adequate. The lack of a general solution for the infinite discrete Gabor transform has limited the usefulness of this digital processing technique, and it has not been applied successfully to creating time-varying energy spectra. See, Qian, et al., "Wigner Distribution Decomposition and Cross-Term Interference Cancellation", UMBC Technical Report No. EER-91-1, University of Maryland, January, 1991.

### SUMMARY OF THE INVENTION

The present invention provides a signal analyzer for generating a time varying spectrum for input signals characterized by frequency components which change in time. The invention can also be characterized as a method for analyzing a signal based on the time varying spectrum.

Thus, according to a first aspect, the present invention comprises a signal analyzer which includes a converter generating a sequence of digital signals representative of an input signal. The sequence of digital signals is supplied to a first processor which computes orthogonal-like discrete Gabor transform coefficients  $C_{m,n}$  in response to the sequence, and a time varying spectrum, termed herein the Gabor spectrum, of the input signal energy in response to the coefficients. Finally, a second processor processes the spectrum for further analysis or display. One particular analysis step for which the time varying spectrum is useful is in partitioning the input signal into separate components. The separate components may then be individually analyzed using any of a variety of techniques.

The first processor includes an input buffer which receives the incoming sequence of digital signals, and supplies those signals in a format appropriate for computation of the coefficients in response to a buffer controller. Similarly, the processor includes an output buffer, which stores a matrix of values representative of the time varying spectrum, in coordination with the processor engine.

The digital signal processor is programmed to compute the coefficients and the time varying spectrum either by a hardware implementation, or software control of a generic processor. The routine is based on the following steps:

- acquiring a sequence of digital signals representative of the input signal;
- sampling the sequence of digital signals to define a plurality of windows of length  $L$ , each window in the plurality including a plurality of digital signals and shifted by length  $AM$  digital signals relative to an adjacent window;
- computing orthogonal-like discrete Gabor transform coefficients  $C_{m,n}$  in sampling intervals  $\Delta N$  and  $\Delta M$ , for  $n=0$  through  $N-1$  for each window  $m$ , and for the plurality of windows  $m=0$  through  $M-1$ , such that  $\Delta N \Delta M$  is less than  $L$ ;
- computing the time-varying spectrum of energy of the input signal in response to the coefficients  $C_{m,n}$ ; and
- analyzing the input signal in response to the time-varying spectrum.

The orthogonal-like discrete Gabor transform coefficients are computed using a non-periodic, localized discrete window function  $h$ , and a discrete auxiliary function  $\gamma$ , similar to  $h$ . The time varying spectrum is computed utilizing a cross-term deleted Wigner-Ville distribution.

According to yet another aspect of the present invention, the discrete window function  $h$  is a gaussian function having a variance  $\sigma^2$  less than or equal to about  $0.5(L/12)^2$ , where  $L$  is a window length used in the computations.

In yet another aspect of the invention, the spectrum is computed utilizing a look-up table of pre-computed factors used in an energy distribution function based on the coefficients. For each coefficient, an update region